

Assessing the Burn Severity of Wildland Fire in Yukon-Charley Rivers National Preserve

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Abstract:

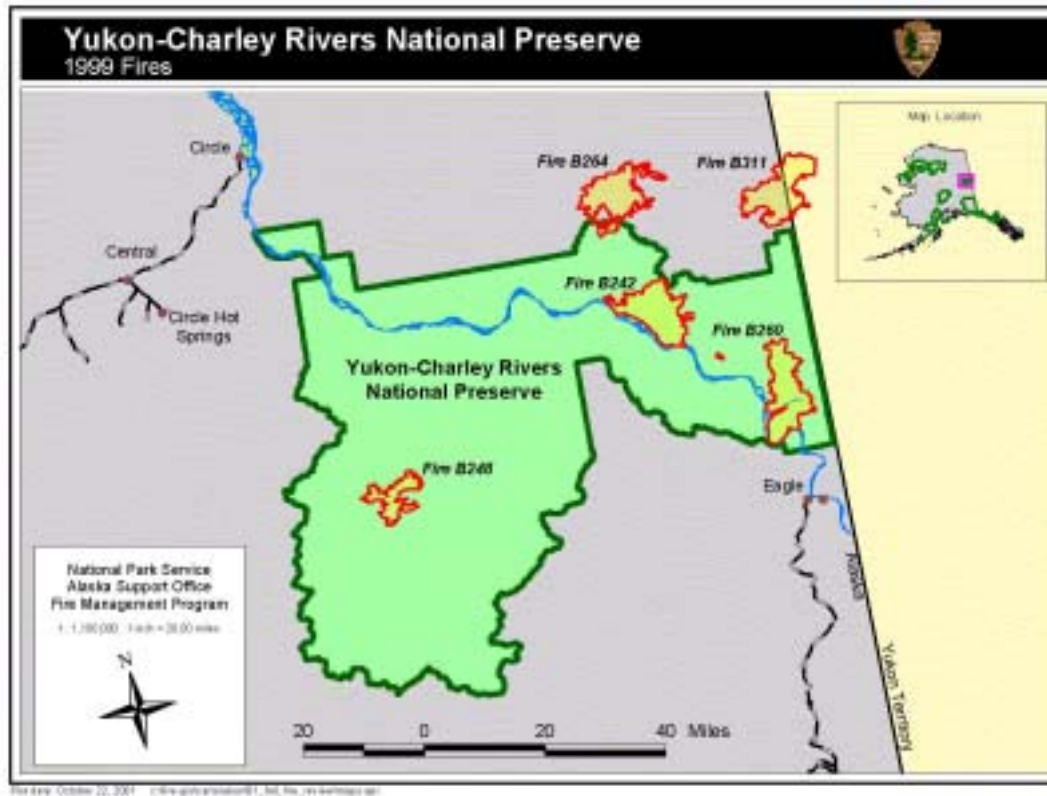
Fire managers are increasingly concerned with the spatial components of a wildland fire incident such as the final fire perimeter and burn severity measurements. Final fire perimeters are important for accurate fire history layers while burn severity data, a measure of the degree of environmental change caused by the fire, can be used to estimate post-fire erosion potential, predict the susceptibility of a burned area to invasion by non-native species, and assess the post-fire vegetation and fuels condition. Effective final fire perimeter and burn severity products can be generated by applying the Normalized Burn Ratio (NBR) to Landsat imagery. The NBR and corresponding Composite Burn Index (CBI) ground truthing techniques have been successfully applied in several parks to generate final fire perimeter and burn severity products. In 2001, NBR burn severity products were generated for a series of fires occurring in and around Yukon-Charley Rivers National Preserve during the 1999 fire season. In order to assess the ability of the NBR to accurately depict burn severity in Yukon-Charley more than 100 CBI plots were installed on three large fires within the preserve boundary. The Normalized Burn Ratio proved to be an adequate means for assessing the burn severity of wildland fire on the 1999 Yukon-Charley fires. Comparisons between CBI plot measures of severity and the Δ NBR yielded R^2 values of 0.75 on fires B242 and B260 and 0.73 on fire B248. The Δ NBR outperformed other potential measures of severity including NDVI (differenced and postfire), band 7 (differenced and postfire), band 4 (differenced and postfire) and band 3 (differenced and postfire).

Introduction:

During the summer of 1999, approximately 120,000 acres burned within the boundaries of Yukon-Charley Rivers National Preserve. While a total of seven fires burned within Yukon-Charley in 1999 the majority of burned acreage (95 %) came from three lightning-caused fires. Fire B242 (Witch fire) and Fire B260 (Jessica fire) burned approximately 46,000 and 48,000 acres in the northeast portion of the preserve along the Yukon River. Fire B248 (Beverly fire) burned approximately 21,000 acres in the south-central portion of the preserve along the Charley River. Fire B264 (Pingo fire) burned approximately 44,000 acres to the north of Yukon-Charley. Around 3,000 acres of the Pingo fire slopped over into Yukon-Charley. Another fire, B311, burned approximately 47,000 acres to the north of Yukon-Charley. Map 1 depicts the nature and extent of fire

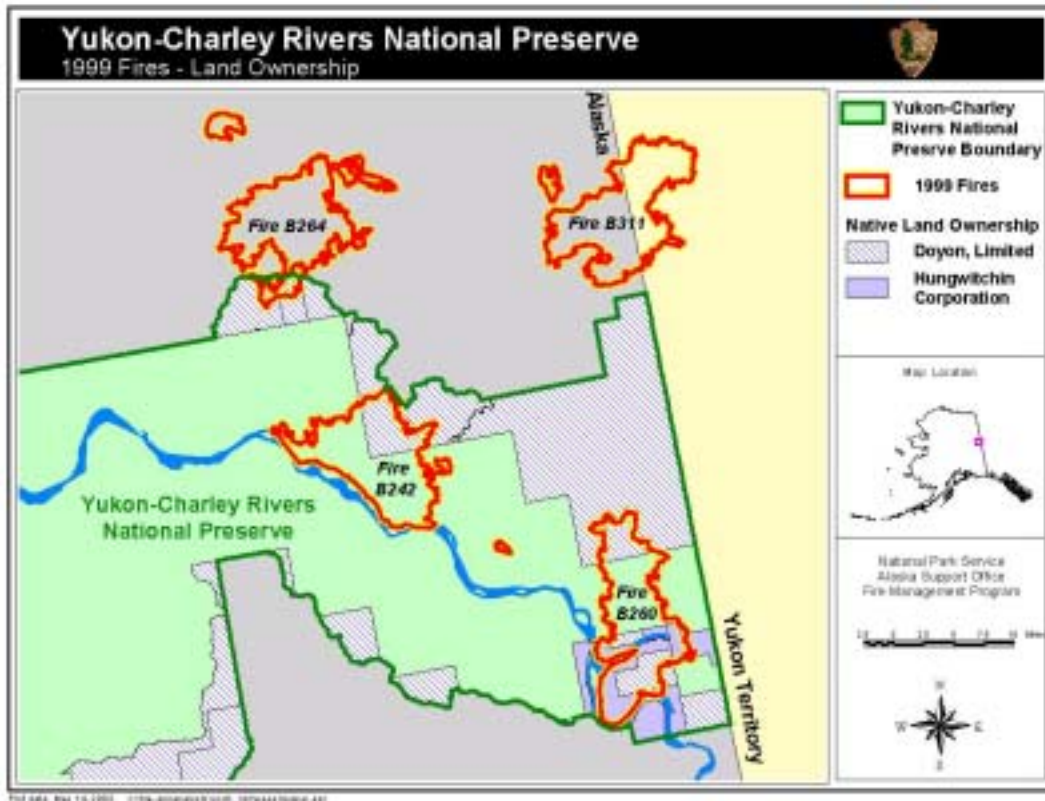
activity in and around Yukon-Charley Rivers National Preserve during the summer of 1999.

Map 1



Fire activity in Yukon-Charley was not limited to lands owned and administered by the National Park Service. Significant portions of Fires B242, B260 and B264 burned on lands administered by the Doyon, Limited Regional Corporation and the Hungwitchin Corporation (Map 2).

Map 2



As fire activity waned, final fire perimeters were gathered using GPS units and incorporated into a GIS for final fire size calculation, display, and storage in fire history layers. While final fire perimeter layers collected using GPS provide an extremely accurate depiction of the final extent of the fire, they contain virtually no information about fire intensity and burn severity characteristics within the fire perimeter. On heterogeneous landscapes like those in Yukon-Charley Rivers National Preserve, fires nearly always burn in a non-uniform manner. Within any given fire, some areas will be unburned while some areas will be drastically changed due to intense scorching. An infinite variety of potential fire effects occur within these two extremes. The final fire perimeter, often the only piece of spatial information collected about the fire, contains no information about the mosaicked pattern of fire effects within the fire perimeter. Photos 1, 2 and 3 serve as an example of fire's varied effects on the landscape.

Photo 1



Photo 2



Photo 3



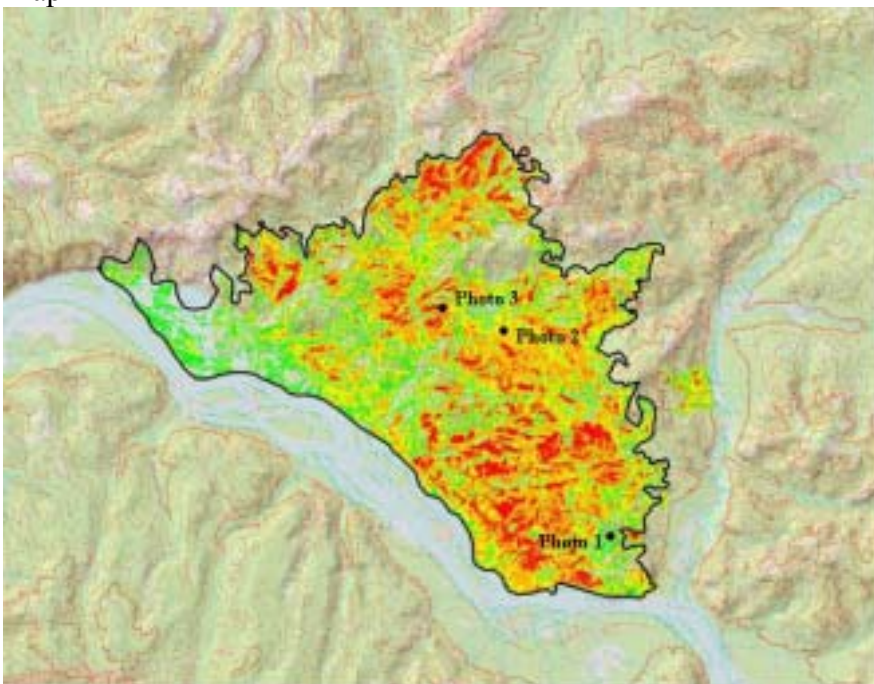
Each of the photos were taken at separate sites within the perimeter of fire B242. Though each photo is from the same fire, they depict vastly different vegetation and burn severity characteristics. Map 3 shows the location where Photos 1, 2 and 3 were taken within Fire B242.

Map 3



GIS datasets containing information about burn severity, a measure of the degree of environmental change caused by fire, within the fire perimeter are highly desirable. Burn severity datasets identify unburned areas within the fire perimeter as well as provide a measure of the likely effect of the fire on the vegetation and fuels condition of burned areas. Map 4 shows an example of a burn severity product for fire B242.

Map 4



Normalized Burn Ratio

The Normalized Burn Ratio (NBR) was used to create GIS burn severity products for the 1999 Yukon-Charley fires. The Normalized Burn Ratio was developed by Carl Key of the USGS Glacier Field Station and Nate Benson of Everglades National Park. The Normalized Burn Ratio uses pre and postfire Landsat imagery to develop a continuous index of burn severity. The NBR is calculated in a manner similar to the Normalized Difference Vegetation Index (NDVI). Whereas NDVI is calculated by generating an index of Landsat bands 3 and 4, the NBR is calculated using an index of Landsat bands 4 and 7. The formula used to derive the Normalized Burn Ratio follows:

$$\text{NBR} = (\text{TM Band 4} - \text{TM Band 7}) / (\text{TM Band 4} + \text{TM Band 7})$$

The Normalized Burn Ratio is calculated for both pre- and post-fire Landsat scenes. Derivation of the NBR yields a floating point dataset with values ranging from -1 to +1. A final differenced NBR (ΔNBR) dataset is derived as follows:

$$\Delta\text{NBR} = \text{Prefire NBR} - \text{Postfire NBR}$$

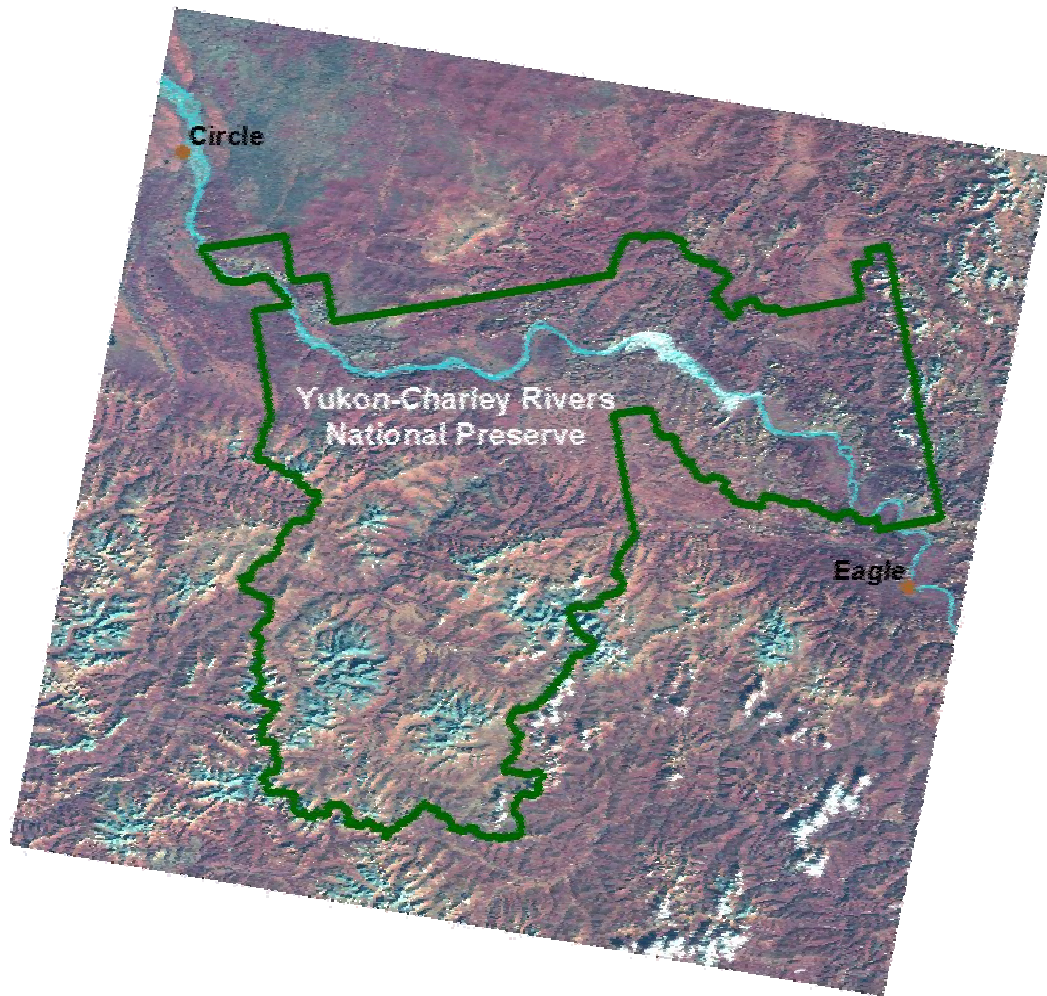
The ΔNBR is the final burn severity product. Derivation of ΔNBR yields a floating point dataset with values ranging from -2 to +2. Delta-NBR datasets are often scaled by 1000 to yield a final burn severity dataset with possible values falling between -2000 and +2000 with increasing values corresponding to increased on the ground burn severity. Generally a threshold exists between 0 and 100 ΔNBR units that marks an approximate breakpoint between burned and unburned areas.

Landsat Imagery

The Normalized Burn Ratio uses Landsat imagery to generate a continuous index of burn severity. Two Landsat scenes are required to complete NBR burn severity processing: a prefire scene and a postfire scene. Currently, there are two Landsat satellites in orbit. Landsat 5 was launched in 1984 and uses the Thematic Mapper sensor to collect remotely sensed images of the earth's surface. Landsat 7, launched in the spring of 1999, is equipped with the Enhanced Thematic Mapper + sensor. Both satellites collect data from six bands in the visible, near-infrared and mid-infrared portion of the electromagnetic spectrum: bands 1-5 and 7. Each also collects data from the thermal infrared portion of the electromagnetic spectrum in band 6. Bands 1-5 and 7 are characterized by a 30-meter minimum cell resolution. Thermal infrared band 6 is characterized by a 120-meter minimum cell resolution in Landsat 5 and a 60-meter cell resolution in Landsat 7. Since NBR datasets are generated using Landsat bands 4 and 7, they are limited to a 30-meter spatial resolution of burn severity.

Landsat data is purchased and distributed in units referred to as scenes. Each scene is approximately 125 miles x 125 miles. Landsat data is organized worldwide into a matrix of scenes, each referred to by a specific path-row combination. Figure 1 shows a Landsat 5 false color scene from path 66 row 14. This particular path row combination happens to be in the immediate vicinity of Yukon-Charley Rivers National Preserve.

Figure 1



Scene Selection Criteria

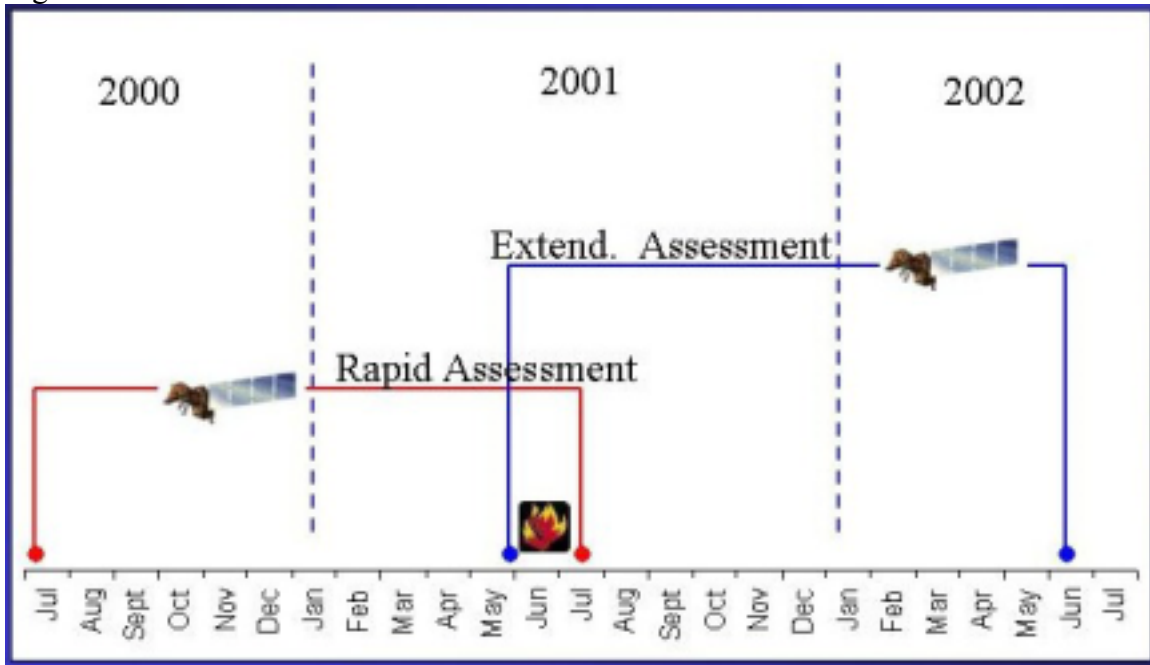
The Normalized Burn Ratio requires Landsat imagery from before a fire and from after a fire. Scene pairs should be captured on or near anniversary dates so that vegetation is in a similar phenological state. By differencing the prefire and postfire images, the unburned/unchanged areas are factored out, highlighting the burned area and the severity differences within it. In order for this change detection to be successful, the unburned vegetation should generally “look” the same in the two images. Comparing Landsat scenes where one scene is in a leaf-off stage and the other is in a leaf on stage (or some other phenological difference) will produce erroneous and misleading burn severity products. If a postfire scene is collected during the first week of September, generally the prefire scene should also be collected from the first week of September.

Ideally, scene pairs will come from consecutive years, with the fire of interest occurring in one of those years. Change detection and severity processing will be most successful if unburned vegetation is in a similar condition. Scene collection from consecutive years or, if possible, from the same year, insures vegetation phenological

differences are minimized. In many instances, it is not possible to locate scene pairs on anniversary dates from consecutive years due to cloud cover. This is particularly true throughout Alaska. In this particular exercise, a postfire scene from 1999 and a prefire scene from 1995 were used. Because of extensive cloud cover during the intervening years, a scene separation of four years was the best opportunity available.

Two types of burn severity assessments can be completed. In an initial assessment, a postfire scene is collected immediately after fire activity ceases. This scene is then compared with a corresponding scene captured during the same period from the year before. As an example, for an Alaskan fire ending in early July of 2001, a postfire scene from mid July 2001 would be compared with a prefire scene from mid July 2000 (Figure 2). In an extended assessment, a postfire scene is not collected until the height of the growing season (period of maximum greenup) following the fire. A prefire scene is then collected from the height of the growing season immediately preceding the fire. In an extended assessment of the Alaska fire ending in early July of 2001, a postfire scene would not be collected until the height of greenup in the following season: early to mid June, 2002. A prefire scene from immediately before the fire, June 2001 would be used for comparison in the extended assessment (Figure 2).

Figure 2



Each assessment has various advantages. Rapid assessments can be completed in a timely manner and offer a good definition of areas burned as well as an accurate final fire perimeter. The extended assessment requires a significant waiting time for processing. However, the extended assessment generally offers the best measure of burn severity. In the postfire scene of the initial assessment, burned areas may look uniformly black and charred. The extended assessment gives the area a chance to recover or bounce back in the aftermath of the fire. Postfire scene capture during the middle of the growing

season following the fire highlights and contrasts the areas of low severity that recover quickly with the areas of high severity that may remain barren for a number of years.

Field verification through the Composite Burn Index

In order to insure return on investment, GIS products generated through remote sensing, like burn-severity, must be field-verified. The Composite Burn Index (CBI) plot methodology was developed to provide some capability to ground-truth remotely sensed burn severity products. CBI plots are ocular in nature and do not involve the collection or removal of park or preserve resources. CBI plots are not permanent and do not involve the placement of markers for use in future visits. Composite Burn Index plot methods were developed by Carl Key, USGS West Glacier Field Station, and Nate Benson, Prescribed Fire Specialist, Everglades National Park.

Ocular estimates related to the degree of environmental change caused by fire in various forest and non-forest strata are made and marked on a field data sheet. Crews make ocular estimates of the degree of environmental change caused by fire on various forest and nonforest vegetative strata. As an example, crews make ocular estimates of the change caused by fire to fuels greater than three inches in diameter with possible options being: unchanged; 5% loss, blackened; 15% loss, deep char; and >30% loss, deep char. In all, up to 22 severity scores are recorded for a variety of measures including change in litter, amount of new serals, % of tall shrubs consumed, etc. Table 1 lists the components for which burn severity scores are gathered in each of five vegetative strata.

Table 1: Components of the Composite Burn Index

Understory Strata

<u>Substrate</u>	<u>Trees and Shrubs < 1 m high</u>	<u>Tall Shrubs / Saplings</u>
Litter	Nonvascular Plants	% Foliage Consumed
Duff	% Living/Resprouting	% Conifers Green
Fuels < 1000 hr	New Serals	% Living/Resprouting
Fuels ≥ 1000 hr	Species Diversity	New Serals
Soil Cover/Color		Species Diversity

Overstory Strata

Intermediate / Subcanopy Trees

% Green (Unaltered)
 % Black (Torch)
 % Brown (Scorch)
 Char Height

Upper Canopy

% Green (Unaltered)
 % Black (Torch)
 % Brown (Scorch)
 Char Height

A score between 0 and 3 is recorded for each component with 0 meaning that the component is unchanged and 3 meaning that the component has either been completely consumed by fire or has been radically changed by fire. If a particular component is not present at a plot, no score is recorded. An overall CBI score is calculated for each plot by averaging the individual severity scores from each of the individual components. This overall CBI score is then cross-referenced with the satellite measure of severity to determine the degree of correlation using a GPS point taken to mark the plot location. A sample CBI field data sheet can be found in Appendix A.

Methods:

Three separate Landsat scenes were required for NBR initial assessment burn severity processing of the 1999 Yukon-Charley fires. Post-fire imagery for all fires was collected in September of 1999 using the Landsat 7 ETM+ sensor. For fires B242, B260, B264 and B311 a post-fire scene from September 12, path 65 row 14 was used. A different postfire scene was used for fire B248 because it was not covered in the scene used for the other fires. A postfire scene from September 10, path 67 row 14 was used for fire B248.

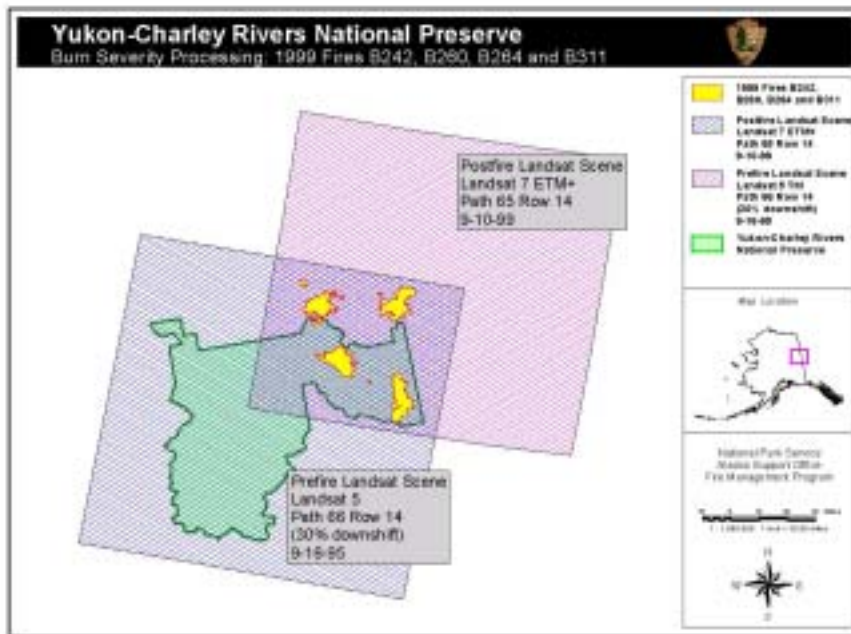
It is difficult to locate cloud-free imagery over Yukon-Charley. A prefire scene from September 1995 was the most recent suitable Landsat image available. This Landsat 5 TM scene, collected September 16, 1995 was used as the prefire image for all fires. The prefire Landsat 5 TM scene was downshifted 30% within path 66 so that it would completely cover Yukon-Charley Rivers National Preserve and the fires of interest. Table 2 summarizes the Landsat 5 and 7 data used for NBR processing of the 1999 Yukon-Charley fires.

Table 2: Imagery Used for NBR Processing of 1999 Yukon-Charley fires

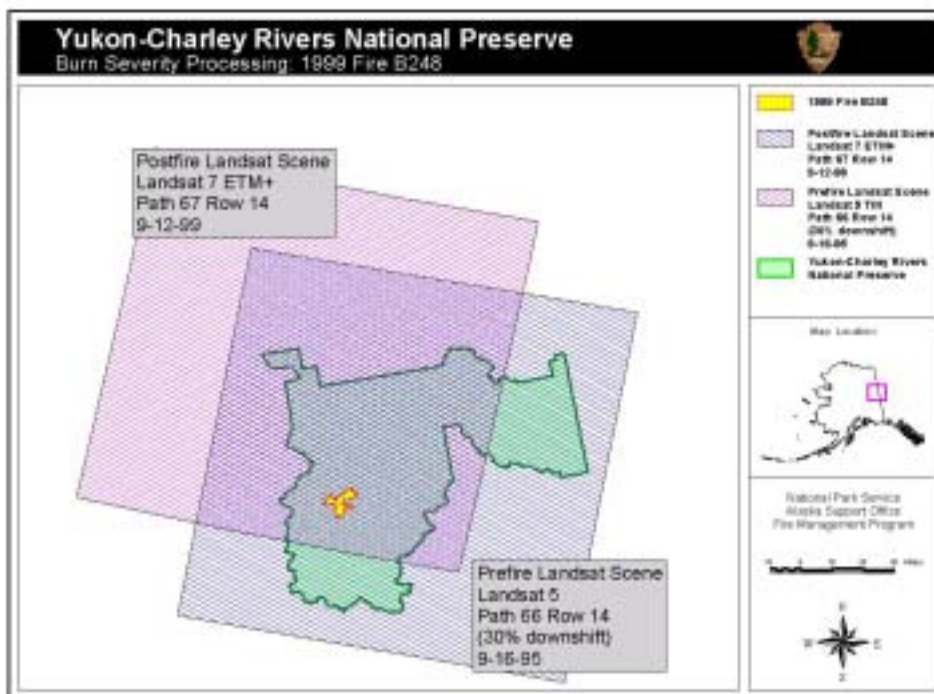
Prefire Imagery				Postfire Imagery			
<i>Fire</i>	<i>Sensor</i>	<i>Path/Row</i>	<i>Collection Date</i>		<i>Sensor</i>	<i>Path Row</i>	<i>Collection Date</i>
B248	Landsat 5 TM	66/14	9/16/95		Landsat 7 ETM+	67/14	9/10/99
B242, B260, B264, B303	Landsat 5 TM	66/14	9/16/95		Landsat 7 ETM+	65/14	9/12/99

Maps 4 and 5 display the spatial extent and overlap of the prefire and postfire imagery used for processing of the 1999 Yukon-Charley fires.

Map 4



Map 5



All Landsat imagery was purchased from the USGS EROS Data Center. Scenes were georeferenced to the Terrain correction level and were resampled using cubic convolution. The Landsat 5 prefire imagery was delivered in the Albers Alaska NAD27

projection. The postfire Landsat 7 imagery was delivered in the Albers Alaska WGS84 projection. The postfire imagery was projected to NAD27 using the ‘project grid’ command in Arc/Info. Nearest neighbor resampling was used when projecting post-fire data.

All Landsat imagery was processed from the original Digital Number values to units of radiance and then units of at-satellite reflectance. Units of Radiance were calculated for each band as follows:

$$\text{Rad}_i = \text{DN}_i * G_b + B_b$$

Where,

Rad_i = Units of Radiance for pixel i

Dn_i = Original Digital Number value of pixel i

G_b = Gain for Band b

B_b = Bias for Band b

Tables 3 and 4 list the Gain and Bias values used to calculate Landsat Bands 3, 4 and 7 in units of radiance for the prefire and postfire imagery.

Table 3: Landsat 5 TM Prefire Scene; Gains and Bias

	Gain	Bias
TM Band 3	0.8057647	-1.1700000
TM Band 4	0.8145490	-1.5100000
TM Band 7	0.0569804	-0.1500000

Table 4: Landsat 7 ETM+ Scenes; Gains and Bias

	Gain	Bias
ETM+ Band 3	0.6192157	-5.0000000
ETM+ Band 4	0.6372549	-5.1000061
ETM+ Band 7	0.0437255	-0.3500004

From units of radiance, units of reflectance were calculated as follows:

$$Ref_i = (Rad_i * \pi * d^2) / (Esi_b * \cos(z_s))$$

Where,

Ref_i = Units of Reflectance for pixel i

Rad_i = Units of Radiance for pixel i

d^2 = Orbital eccentricity factor

Esi_b = Exoatmospheric solar irradiance constant per band

Z_s = Sun zenith angle per scene

Table 5 lists the orbital eccentricity factor and sun zenith angle values used for each scene.

Table 5: Orbital Eccentricity Factor and Sun Zenith Angle values per scene

Scene	Date	d^2	Z_s
Prefire Landsat 5 TM	9/16/1995	1.0114	65
Postfire Landsat 7 ETM+	9/10/1999	1.0143	60.95
Postfire Landsat 7 ETM+	9/12/1999	1.0132	61.69

Table 6 lists the Esi values used for each band for reflectance calculations of prefire and postfire imagery.

Table 6: Exoatmospheric Solar Irradiance Constants per Band per Sensor

Sensor	Band 3 Esi	Band 4 Esi	Band 7 Esi
Prefire Landsat 5 TM	1555	1047	80.53
Postfire Landsat 7 ETM+	1555	1047	80.53

Atmospheric/Sensor Radiometric Normalization

The prefire Landsat 5 TM data was normalized to postfire Landsat 7 data to correct for differences associated with sensor characteristics and atmospheric conditions between the two dates. Pseudoinvariant (unchanging) pixels were identified in all scenes. Pseudoinvariant samples were gathered from a variety of areas including water (turbid and unturbid), rock and snow. For all sites, the Landsat 5 and Landsat 7 data were analyzed using the regression feature in Microsoft Office 2000 Excel. Regression equations were generated and used to normalize the Landsat 5 imagery to the Landsat 7 imagery. Two normalizations were completed. In the first, the Landsat 5 (9-16-1995) scene was matched with the Landsat 7 (9-12-1999) scene. In the second, the Landsat 5 (9-16-1995) scene was matched with the Landsat 7 (9-10-1999) scene. Table 7 summarizes the values used to normalize the prefire Landsat 5 imagery to the corresponding postfire Landsat 7 imagery.

Table 7: Slope and Intercept values for Atmospheric/Sensor Normalization of Prefire Landsat 5 TM Imagery

Fires	Prefire Scene	Postfire Scene	Band	Slope	Intercept
B242, B260, B264, B311	9/16/1995	9/10/1999	3	0.90762	0.01555
B242, B260, B264, B311	9/16/1995	9/10/1999	4	1.068693	0.001865
B242, B260, B264, B311	9/16/1995	9/10/1999	7	0.874017	0.022991
B248	9/16/1995	9/12/1999	4	0.983006	0.026811
B248	9/16/1995	9/12/1999	7	0.883056	0.025228

Normalized Burn Ratio

Pre and Postfire Normalized Burn Ratio datasets were calculated using band inputs in units of reflectance. Prefire reflectance inputs were normalized for atmospheric/sensor differences between the Landsat 5 and Landsat 7 data. Prefire and Postfire NBR datasets were derived as follows:

$$NBR_{pre} = (TM \text{ Band } 4_{pre} - TM \text{ Band } 7_{pre}) / (TM \text{ Band } 4_{pre} + TM \text{ Band } 7_{pre})$$

Where,

NBR_{pre} = Prefire Normalized Burn Ratio

TM Band 4_{pre} = Prefire Band 4 processed to units of reflectance and normalized for atmospheric/sensor effects

TM Band 7_{pre} = Prefire Band 7 processed to units of reflectance and normalized for atmospheric/sensor effects

$$NBR_{post} = (TM \text{ Band } 4_{post} - TM \text{ Band } 7_{post}) / (TM \text{ Band } 4_{post} + TM \text{ Band } 7_{post})$$

Where,

NBR_{post} = Postfire Normalized Burn Ratio

TM Band 4_{post} = Postfire Band 4 processed to units of reflectance

TM Band 7_{post} = Postfire Band 7 processed to units of reflectance

The final ΔNBR burn severity dataset was generated by differencing the prefire and postfire NBR datasets:

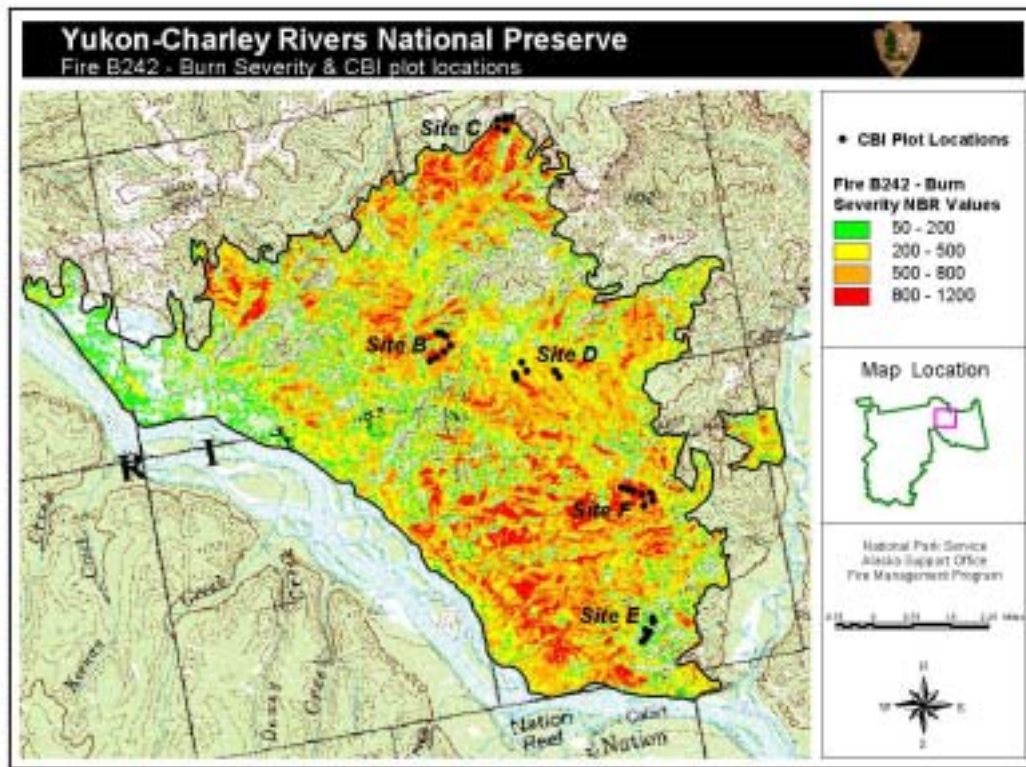
$$\Delta\text{NBR} = \text{NBR}_{\text{pre}} - \text{NBR}_{\text{post}}$$

Composite Burn Index

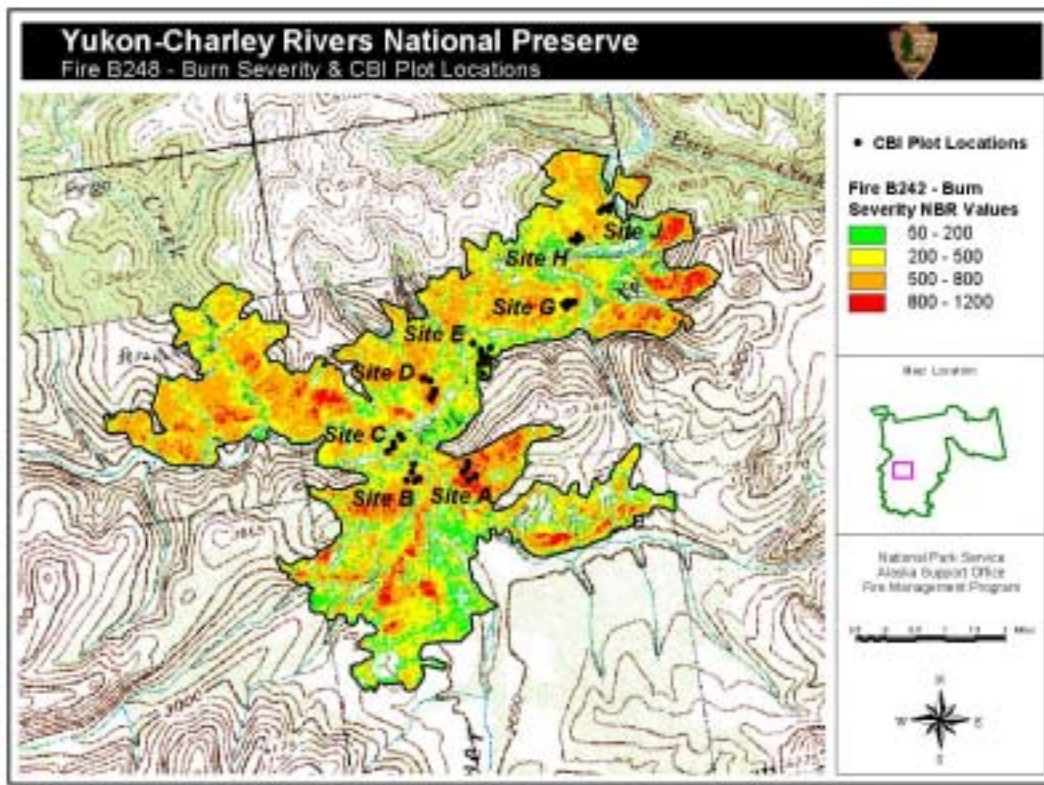
During the summer of 2001, NBR burn severity datasets were field-validated in Yukon-Charley Rivers National Preserve using Composite Burn Index (CBI) plots. A total of 119 CBI plots were installed on fires B242, B248 and B260. Thirty-four plots were installed on fire B242. Forty plots were installed on fire B248. Forty-seven plots were installed on fire B260. CBI plots were installed by fire management staff from Yukon-Charley Rivers National Preserve and the National Park Service Alaska Support Office. Plots on fires B242 and B260 were visited by helicopter. Plots on fire B248 were visited by boat along the Charley River.

Plot locations were pre-determined to insure sampling of the full range of burn severity levels and vegetation types within the various fires. Special thanks are owed to the Doyon, Limited Regional Corporation for allowing park staff to gather CBI plot data on their lands. In all cases eight to ten plot locations were clustered around a central helicopter or boat landing site. Maps 6, 7 and 8 display the delta NBR burn severity values, the landing sites and the locations of CBI plots on fire B242, B248 and B260.

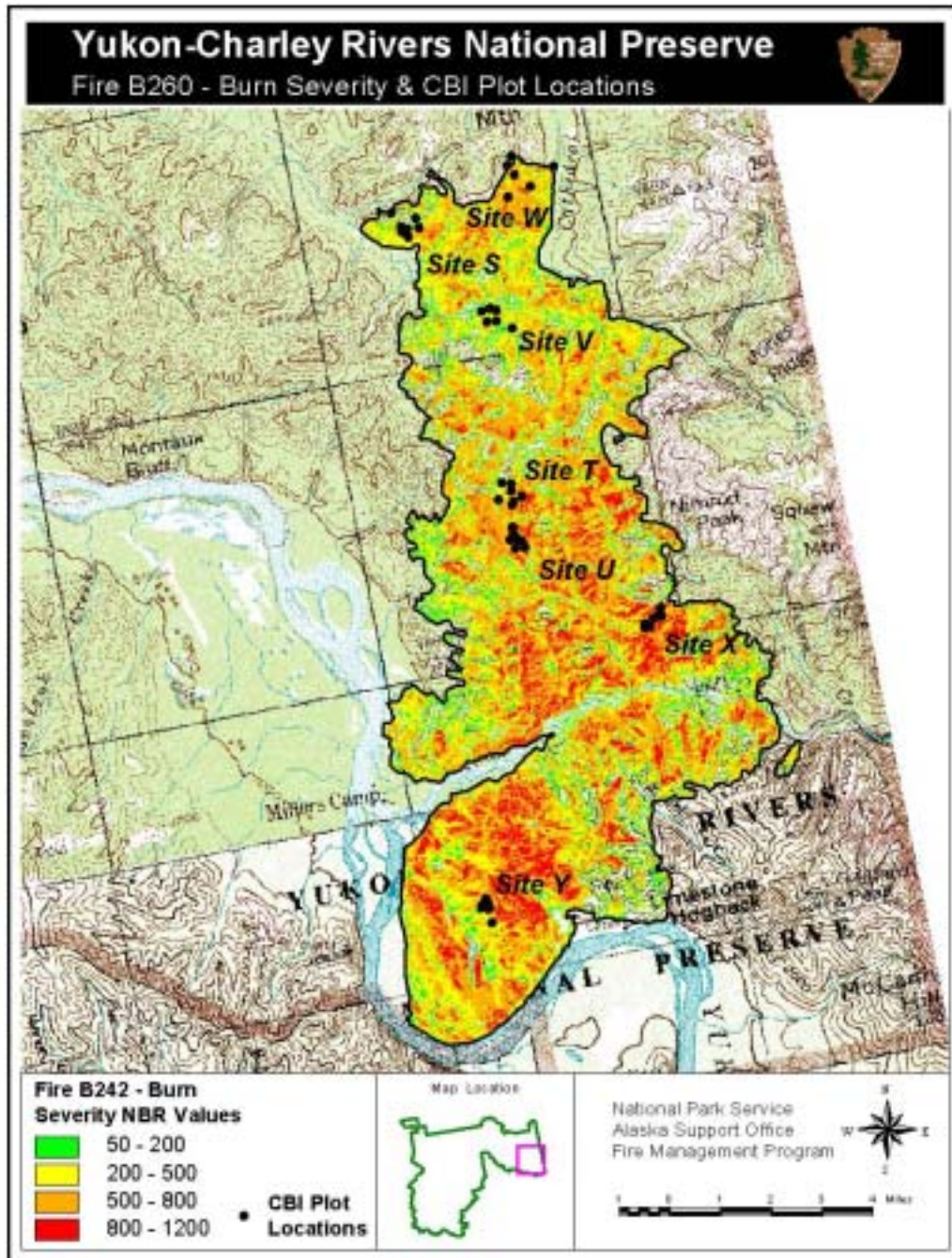
Map 6



Map 7



Map 8



Plot locations were marked using Garmin GPS III+ GPS units. Position Dilution of Precision (PDOP) values were always less than 5 when GPS points were collected. In addition GPS locations were averaged using 100 individual points. Four digital photos were also taken at each plot.

The CBI plot data was entered into a Microsoft Access 2000 database. The digital photos collected at each site were also linked to a plot form in the Access database. A shapefile of plot locations and CBI data was created from the Access database. This CBI point shapefile was then compared with the 30-meter raster burn severity dataset. NBR values were extracted from the cell in which each plot falls using the Arcview Grid Analyst extension. Correlation and r-square values between CBI scores and NBR values were derived using the ESRI bivariate regression script for Arcview.

Results:

Results for the three fires are broken apart into two groups. Results for the degree of correlation between NBR and CBI measures of severity for fires B242 and B260 were generated and are reported separately from results for fire B248. This was done for two reasons. Different sets of imagery, and thus different image processing parameters, were used to generate NBR burn severity data for the two groups. Fires B242 and B260 used a postfire Landsat scene collected September 10. A postfire scene from September 12 was used for processing of fire B248. The two groups are also in different vegetation and habitat types. Table 8 lists the dominant vegetation types encountered at the CBI plots on the various fires. Vegetation types are organized by the landing site location around which plots were clustered.

Table 8: Dominant Vegetation types at CBI plot locations

Fire B242 Prefire Vegetation Type

Site B	Open Needleleaf, Closed Mixed Needleleaf/Deciduous
Site C	Open Needleleaf
Site D	Open Needleleaf
Site E	Closed Deciduous, Closed Mixed Needleleaf/Deciduous
Site F	Open Needleleaf, Closed Mixed Needleleaf/Deciduous

Fire B248 Prefire Vegetation Type

Site A	Open Needleleaf, Woodland Needleleaf
Site B	Open Needleleaf, Woodland Needleleaf, Low Shrub -Tussock
Site C	Open Needleleaf, Woodland Needleleaf
Site D	Open Needleleaf
Site E	Open Needleleaf, Woodland Needleleaf
Site G	Low Shrub - Tussock, Low Shrub, Open Needleleaf
Site H	Low Shrub, Woodland Needleleaf, Dwarf Shrub, Low Shrub - Tussock, Sparsely Vegetated
Site J	Low Shrub - Tussock, Low Shrub, Open Needleleaf, Woodland Needleleaf, Sparsely Vegetated

Fire B260 Prefire Vegetation Type

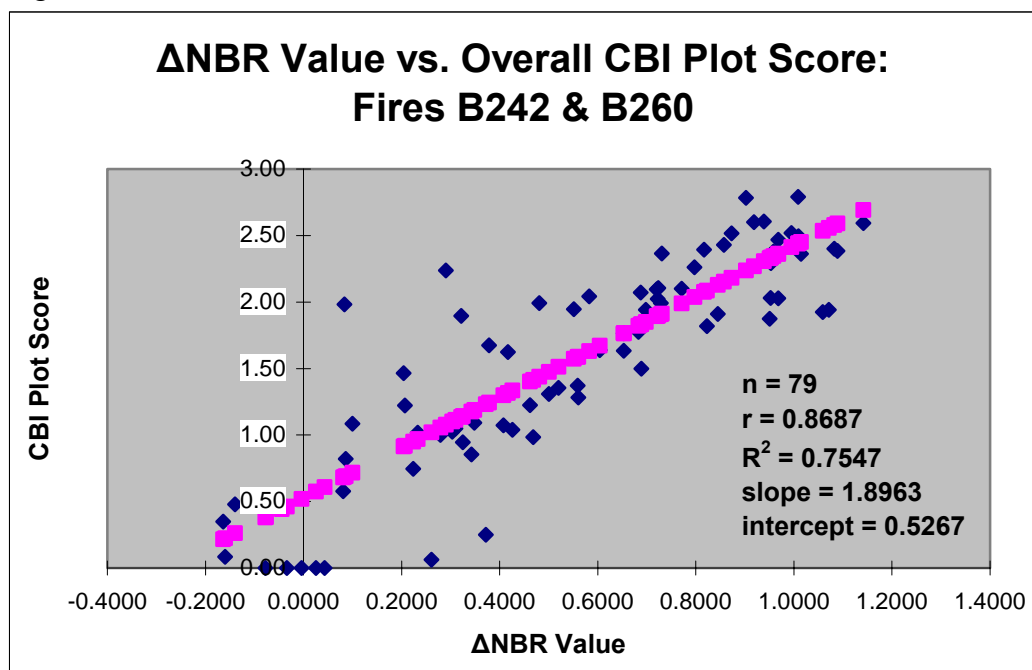
Site S	Open Needleleaf, Terrain Shadow, Woodland Needleleaf, Low Shrub, Low Shrub - Tussock
Site T	Open Needleleaf, Woodland Needleleaf, Dwarf Shrub, Low Shrub - Tussock, Low Shrub, Low Shrub - Tussock, Tall Shrub
Site U	Open Needleleaf, Closed Mixed Needleleaf/Deciduous
Site V	Open Needleleaf, Woodland Needleleaf
Site W	Open Needleleaf, Woodland Needleleaf, Dwarf Shrub, Low Shrub - Tussock, Low Shrub
Site X	Open Needleleaf, Closed Needleleaf, Closed Mixed Needleleaf/Deciduous
Site Y	Open Needleleaf, Woodland Needleleaf

Vegetation information was obtained from the 1997 NPS Yukon-Charley Landcover Layer. Open needleleaf vegetation types dominate all plots on fires B242 and B260. Open needleleaf vegetation types are also found at plot locations of fire B248. However, Fire B248 also contains a number of plots dominated by Low Shrub and Low Shrub – Tussock vegetation types. Fire B248 is also in a different habitat type from fires B242 and B260. Fire B248 is approximately 45 miles away from Fire B242 in the higher elevations of the upper Charley River basin. A separate analysis of Fire B248 from Fires B242 and B260 permits analysis of the application of the NBR to two separate and distinct portions of Yukon-Charley Rivers National Preserve.

Fires B242 and B260

A linear regression between Δ NBR and CBI measures of severity is shown in Figure 3.

Figure 3



A linear regression between ΔNBR and CBI scores yields an R^2 value of 0.7547. This means that 75.47% of the variation in CBI ground measures of severity is explained by the ΔNBR satellite measure of severity. The other 25.53% is explained by error.

In an effort to compare different methods of assessing burn severity, CBI values for all plots in Fires B242 and B260 were compared with a number of remotely sensed measures of burn severity. Along with the ΔNBR , CBI scores were also compared with postfire band 3, differenced band 3, postfire band 4, differenced band 4, postfire band 7, differenced band 7, postfire NBR, postfire NDVI and differenced NDVI. All measures of severity were derived using units of reflectance. All differenced values were derived by subtracting the postfire value from the prefire value. For example,

$$\text{Delta NDVI} = \text{preNDVI} - \text{postNDVI}$$

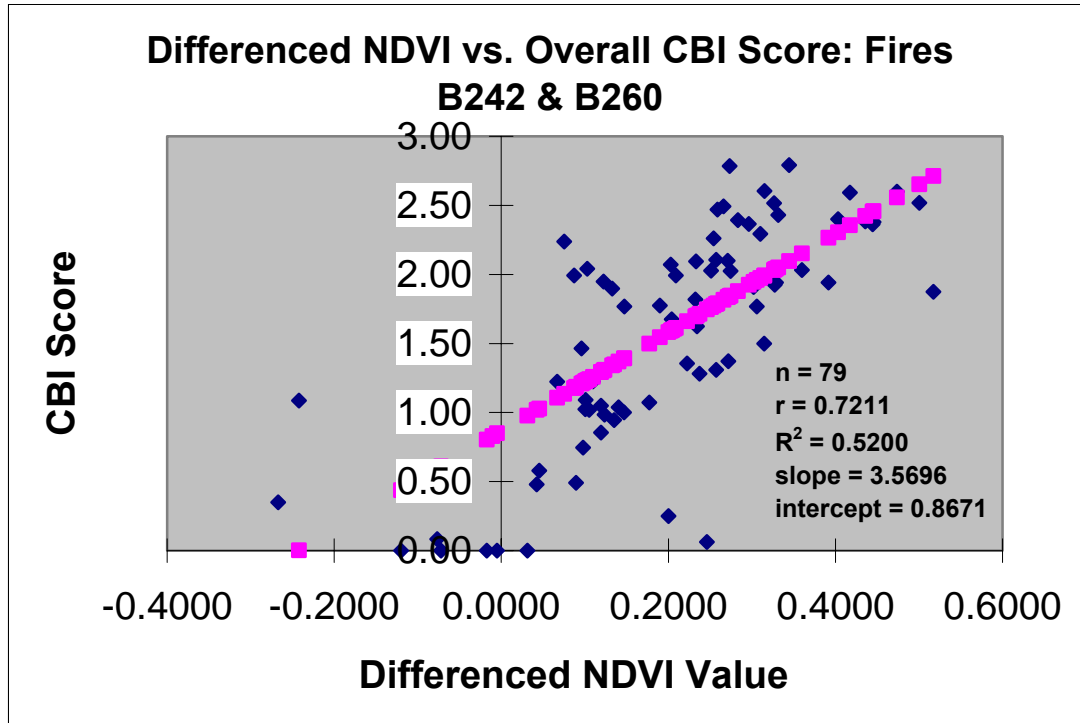
All 79 CBI plots from fires B242 and B260 were used for all regressions. Table 9 summarizes the comparisons made and calculated R^2 values.

Table 9: Regressions between various remotely sensed measures of severity and overall CBI scores on Fires B242 and B260

Dataset	R^2 Value
Postfire Band 3	0.0451739
Differenced Band 3	0.0565048
Postfire Band 4	0.26387
Differenced Band 4	0.465138
Postfire Band 7	0.292467
Differenced Band 7	0.539985
Postfire NBR	0.758395
Differenced NBR	0.754725
Postfire NDVI	0.370103
Differenced NDVI	0.520084

A linear regression between overall CBI scores and differenced NDVI measures of severity is shown in Figure 4.

Figure 4



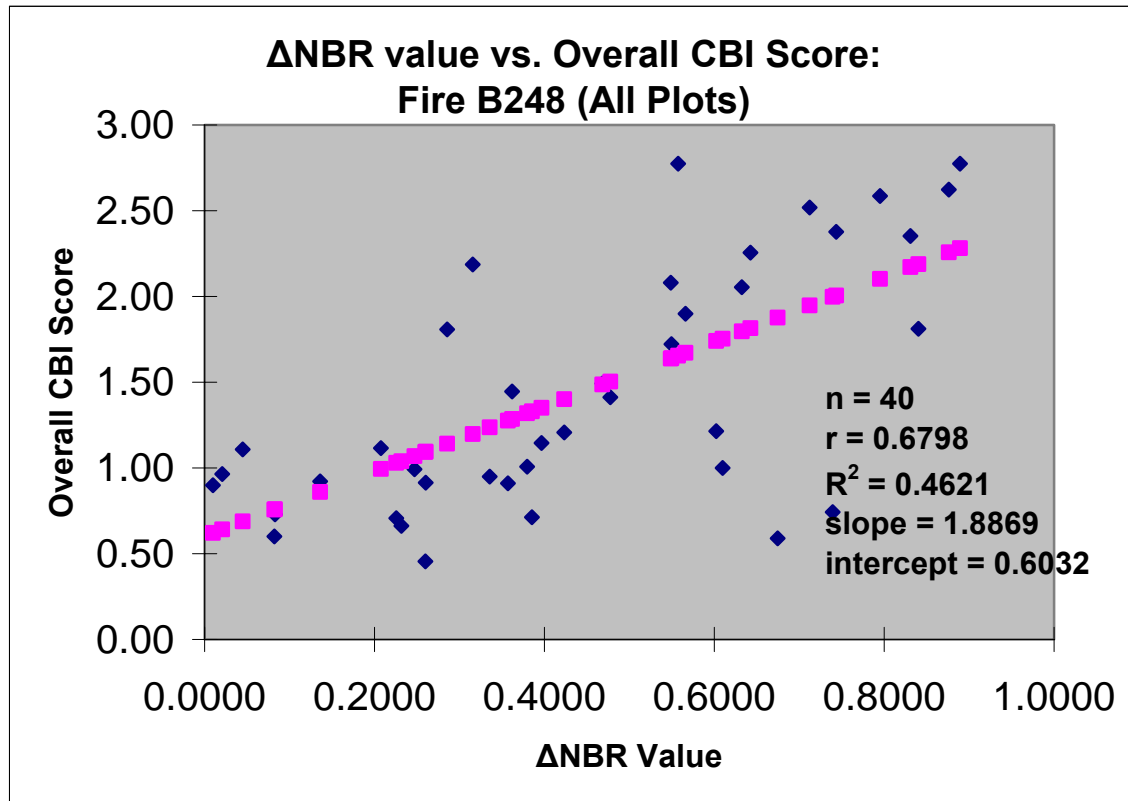
For fires B242 and B260, postfire NBR and differenced NBR offered the best measures of burn severity when compared with field measures of severity as recorded in CBI plots. Both the postfire NBR and differenced NBR datasets exhibited R^2 values of around 0.75 when compared with CBI scores. Differenced NDVI, differenced band 4, and differenced band 7 offered less satisfying measures of severity with R^2 values ranging from 0.46 to 0.53. Postfire band 4, postfire band 7, and postfire NDVI generated R^2 values ranging from 0.37 to 0.26. Finally, differenced band 3 and postfire band 3 were the worst measures of burn severity with R^2 values around 0.05.

A comparison was also made between Δ NBR datasets generated with and without an atmospheric/sensor normalization of the prefire data. The regression between CBI scores and Δ NBR data generated without radiometric normalization yielded an R^2 value of 0.61958, significantly lower than the value of 0.7547 achieved with normalized prefire data. In this case, radiometric normalization of prefire data yielded significantly better results.

Fire B248

A linear regression between Δ NBR and CBI measures of severity is shown in Figure 5.

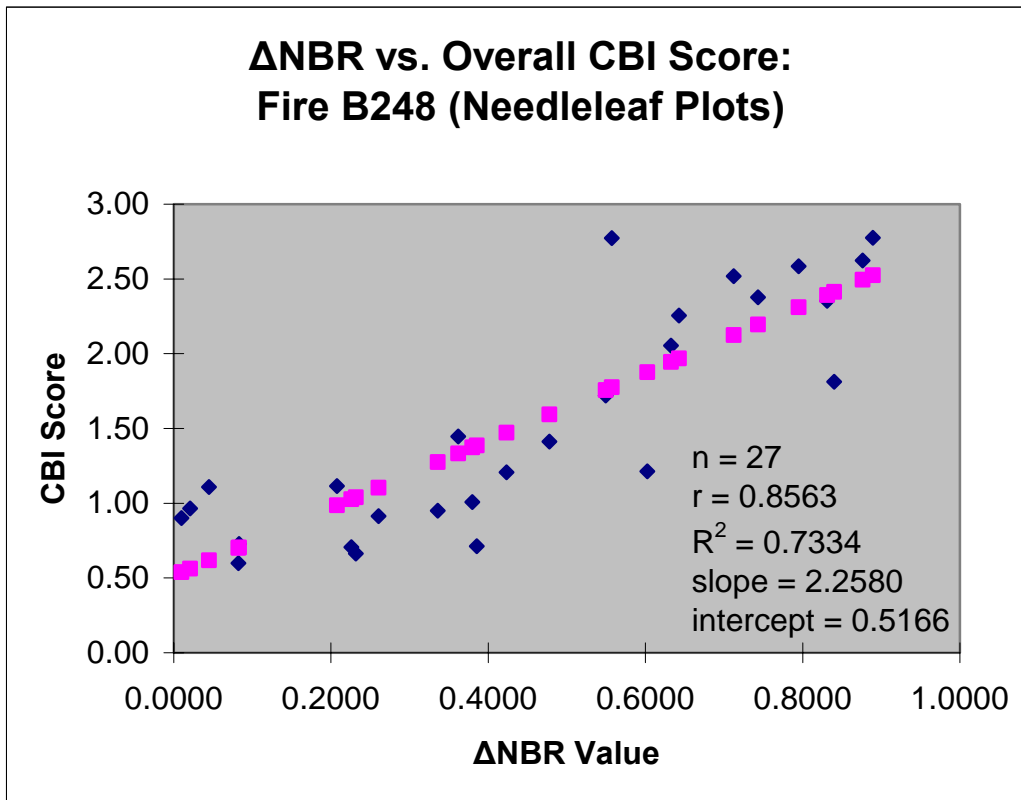
Figure 5



A linear regression between Δ NBR and CBI scores on fire B248 yields an R^2 value of 0.4621. This is significantly lower than the degree of correlation observed on fires B242 and B260. This may be due to the prevalence of nonforest open shrub vegetation types on fire B248.

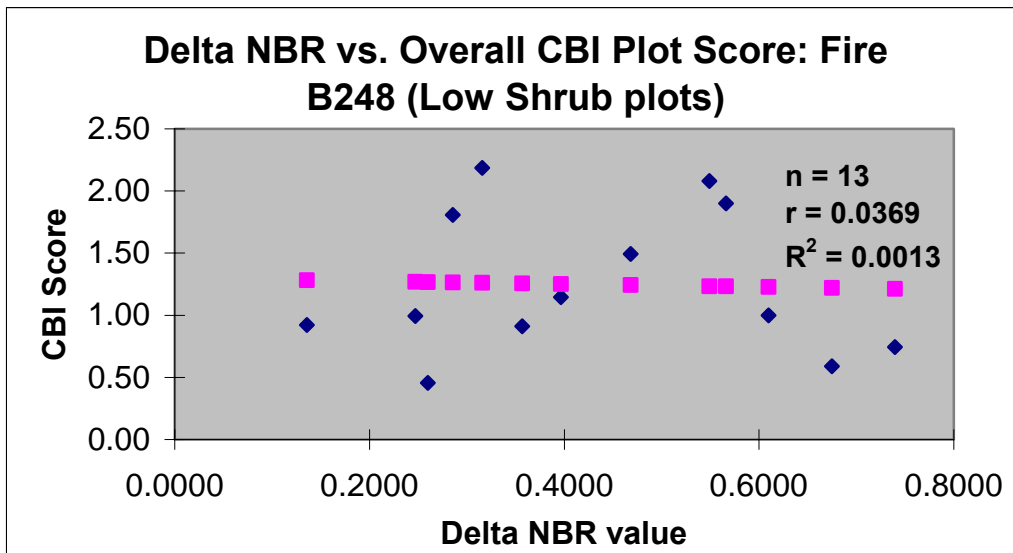
As shown in Table 8, CBI plots were installed in a variety of vegetation types on fire B248. While fires B242 and B260 are dominated by an assortment of needleleaf vegetation type, nonforest low shrub vegetation types are found extensively on fire B248. Plot sampling on fire B248 was split between needleleaf and low shrub vegetation types. Thirteen plots at sites G, H and J were located almost exclusively in low shrub vegetation types. The other 27 plots at sites A, B, C, D and E were located in predominantly Open and Woodland Needleleaf vegetation types. A regression between Δ NBR data and CBI scores from the 27 needleleaf vegetation plots is shown in Figure 6.

Figure 6



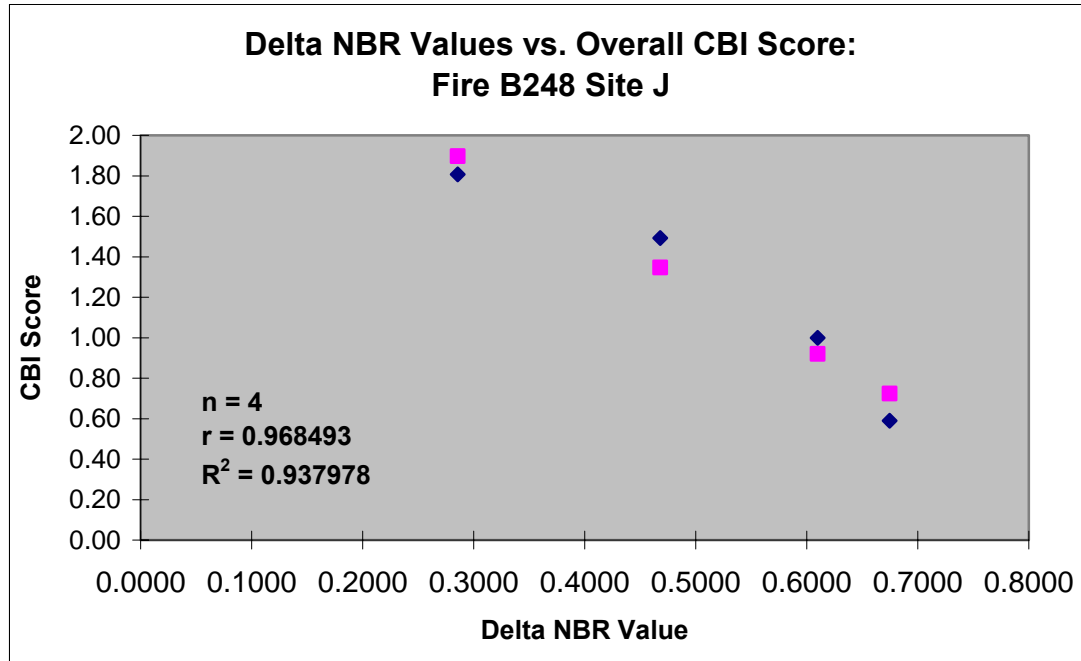
Removing the low shrub CBI plots yields a significantly improved R^2 value of 0.7334. This is very much in agreement with the value observed on fires B242 and B260 (0.7547). A regression of just the 13 low shrub CBI plots with Δ NBR yields a pitiful R^2 value of 0.001369 (Figure 7).

Figure 7



CBI Plots at site J on fire B248 actually exhibited an inverse relationship with Δ NBR values. For CBI plots at site J, as Δ NBR values increased, ground measures of severity decreased (Figure 8).

Figure 8



A comparison was also made of the ability of a number of remotely sensed datasets to depict burn severity on fire B248. Along with the Δ NBR, CBI scores were also compared with postfire band 4, differenced band 4, postfire band 7, differenced band 7 and postfire NBR. Only the 27 needleleaf CBI plots were used for regressions. Table 10 summarizes the comparisons made and calculated R^2 values.

Table 10: Regressions between various remotely sensed measures of severity and overall CBI scores on Fire B248

Dataset	R ² Value
Postfire Band 4	0.204818
Differenced Band 4	0.407049
Postfire Band 7	0.684016
Differenced Band 7	0.659523
Postfire NBR	0.701965
Differenced NBR	0.733415

For fire B248, Δ NBR and postfire NBR offered the best measures of burn severity with R^2 values ranging from 0.73 to 0.70. Differenced band 7 and postfire band 7 had slightly lower values ranging from 0.66 to 0.68. Band 3 and NDVI datasets were not correlated to CBI data for fire B248 because they were not generated. Delta NBR datasets created with out radiometric normalization of prefire imagery generated R^2 values of 0.725822, marginally less than values generated with radiometric normalization.

Discussion:

Overall the Normalized Burn Ratio performed quite well as an indicator of burn severity on the 1999 Yukon-Charley fires. On fires B242 and B260, linear regressions between NBR values and CBI severity scores generated R^2 values of around 0.75 for both the Δ NBR and postfire NBR datasets. Similar values were also found on fire B248 in an analysis of forested needleleaf plots. Results in Yukon-Charley are comparable to results obtained in a similar analysis of fire's occurring in Glacier National Park, MT in 1994. In an initial assessment of burn severity the relationship between CBI plots and Δ NBR values yielded an R^2 value of 0.6374. An extended assessment of the same variables yielded an R^2 value of 0.8428 (Key and Benson, 2001, <<http://nrm.sc.usgs.gov/research/ndbr.htm>>). The initial assessment of 1999 fires in Yukon-Charley compares favorably with the initial assessment of 1994 fires in Glacier. Generally, extended assessments offer better results than initial assessments. It would not be unexpected if an extended assessment of the 1999 Yukon-Charley fires yielded results comparable to those found in the Glacier extended assessment. An extended assessment could not be performed in Yukon-Charley because of a general lack of cloud-free imagery over the area during the summer of 2000. An extended assessment may be possible using postfire imagery from the 2001 season. Such an exercise would likely yield lower burn severity levels due to the two year interval between fire occurrence and postfire scene capture.

For all fires, NBR values exhibited the highest level of correlation with CBI scores. Results using NDVI and Landsat bands 3, 4 and 7 were generally less favorable than results obtained using the NBR. Generally, NDVI and band 7 datasets (differenced and postfire) performed one tier down from the results obtained using the NBR. While Δ NBR R^2 values typically hovered between 0.73 and 0.75, NDVI and band 7 differenced measures generated R^2 values in the range of 0.52 to 0.54 on fires B242 and B260. On fire B248, differenced band 7 generated R^2 values of 0.6595. Differenced band 4 data performed one degree of measure worse with R^2 values in the range of 0.40 to 0.46. Data from band 3 (differenced and postfire) exhibited the lowest R^2 values of the datasets examined. Table 9 summarizes the results obtained for each data type on the independent analyses of fires B242/B260 and fire B248. In an effort to simplify, datasets offering relatively similar results are broken out into tiers.

Table 9: Relative Rankings of the degree of correlation between remotely sensed data and CBI measures of burn severity

	Rankings	R² Fires B242 and B260	R² Fire B248
Tier I	Differenced NBR	0.75	0.73
	Postfire NBR	0.76	0.70
Tier II	Differenced Band 7	0.54	0.66
	Postfire Band 7	0.29	0.68
	Differenced NDVI	0.52	na
	Postfire NDVI	0.37	na
Tier III	Differenced Band 4	0.46	0.40
	Postfire Band 4	0.26	0.20
Tier IV	Differenced Band 3	0.06	na
	Postfire Band 3	0.05	na

On all fires, results for the differenced NBR and postfire NBR datasets are quite similar. This begs the question: Is it necessary to generate a differenced NBR dataset using a prefire image when a postfire NBR image by itself may perform just as well? No doubt, the postfire NBR image contains a great deal of information about burn severity by itself. However, there are still advantages to acquiring a prefire scene and generating Δ NBR datasets. The operational definition of burn severity is that it is the degree of environmental change caused by fire. There cannot be an accurate distinction of the degree of change caused by fire without prefire information. While the postfire NBR data alone may correctly identify areas that burned more intensely than others, it is unable to quantify the degree of change caused by fire. As an example, rocky or barren areas within the fire perimeter (or outside the perimeter) may look burned in postfire NBR data. The Δ NBR's reliance on prefire imagery for change detection will factor out these and other "burned-like" areas so that they correctly appear unchanged. Differenced NBR data also generally exhibits a greater range of values within burned areas, thus providing more contrast between burn severity levels (Key and Benson, 2001, <<http://nrmssc.usgs.gov/research/ndbr.htm>>). In Alaska it is often difficult or impossible to find adequate pre and postfire imagery. While the Δ NBR should remain the true measure of burn severity, postfire NBR imagery alone may provide a useful glimpse of burn severity when prefire imagery is not available.

Generally, the Normalized Burn Ratio provided an accurate measure of burn severity on the 1999 Yukon-Charley fires. However, as shown in fire B248, the NBR's capabilities did not extend to all vegetation types. The NBR was not able to accurately describe burn severity in areas of low shrub vegetation on fire B248. The R² value on low shrub sites was 0.0013 while the R² value on forested needleleaf plots was 0.7334. Examples of the forested needleleaf and low shrub vegetation types on fire B248 are shown in photos 4 and 5.

Photo 4: Site D ; Plot 3



Photo 5: Site G; Plot 4



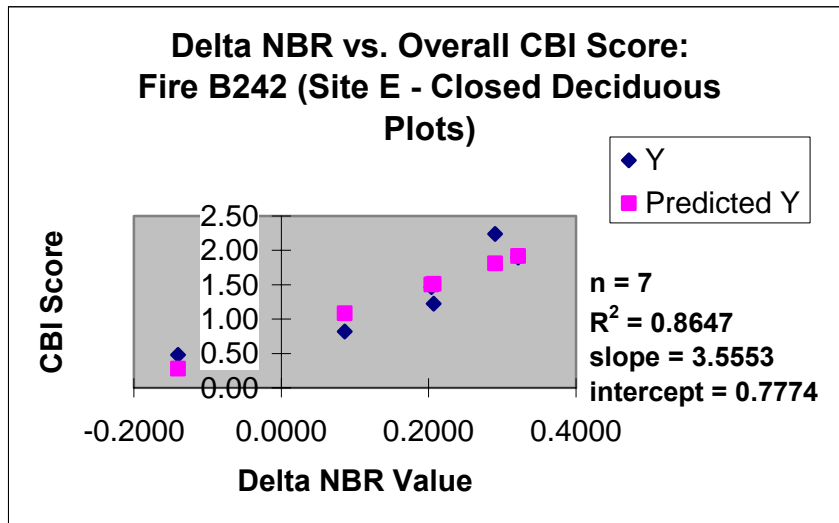
Slightly different vegetation types were also encountered on fires B242 and B260. Though they did not cause problems like in fire B248, it is evident that the NBR and CBI respond in slightly different ways, based on vegetation type. While most CBI plots on fires B242 and B260 were located in Open and Woodland Needleleaf vegetation types, plots at site E on fire B242 were located in a predominantly Closed Deciduous vegetation type (Photo 6).

Photo 6: Fire B242; Site E; Plot 3



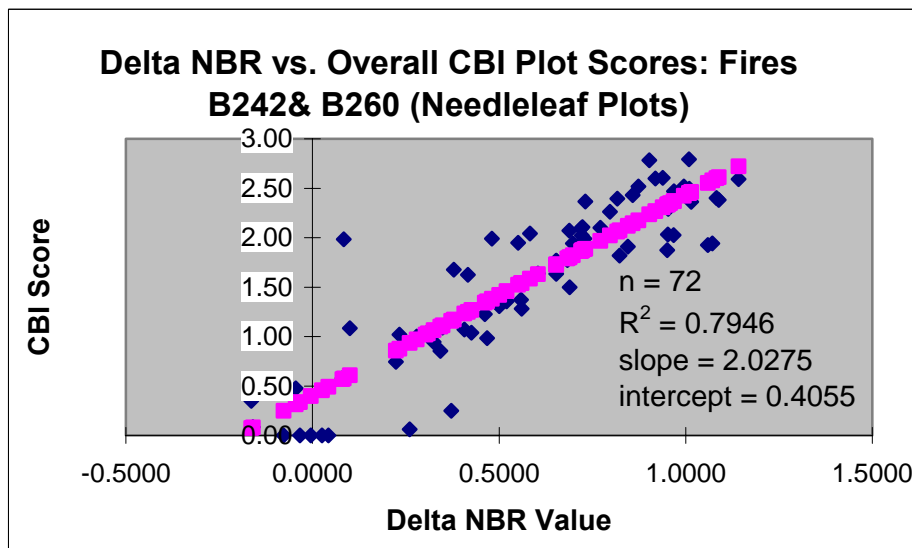
Figure 9 shows a regression between Δ NBR values and CBI scores from plots at site E.

Figure 9



The correlation between CBI scores at the Closed Deciduous plots and Δ NBR values is outstanding. A regression for the remaining predominantly needleleaf plots is shown in Figure 10.

Figure 10



Removing the closed deciduous plots increases the R^2 value from 0.73 to 0.79. In addition the slope and intercept characteristics of the regression lines for needleleaf plots and deciduous plots are significantly different. The regression line for needleleaf plots on fires B242 and B260 has a slope of 2.02 and a y-intercept of 0.40. The regression line for closed deciduous plots has a slope of 3.55 and an intercept of 0.77. Of special interest,

the regression line generated for needleleaf plots on fire B248 has a slope of 2.25 and a y-intercept of 0.51. The characteristics for the linear regression of needleleaf plots on fire B248 is very similar to the characteristics for the linear regression of needleleaf plots on fire B248.

While the NBR was able to accurately depict burn severity in needleleaf and closed deciduous vegetation types it was not able to depict burn severity in low shrub vegetation types. More work is required to understand the capabilities and response of the Normalized Burn Ratio in different vegetation types.

Conclusion:

The Normalized Burn Ratio proved to be an adequate means for assessing the burn severity of wildland fire on the 1999 Yukon-Charley fires. Comparisons between CBI plot measures of severity and the Δ NBR yielded R^2 values of 0.75 on fires B242 and B260 and 0.73 on fire B248. The Δ NBR outperformed other potential measures of severity including NDVI (differenced and postfire), band 7 (differenced and postfire), band 4 (differenced and postfire) and band 3 (differenced and postfire). Problems were encountered applying the Δ NBR to burn severity assessments in low shrub vegetation types on fires B248. Additional work and analysis is required to understand the Normalized Burn Ratios capabilities and response characteristics in different vegetation types.

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